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TRANSMITTAL LETTER

Transmitted herewith for filing under 37 CFR §1.53(b) is the patent application of:

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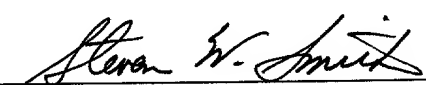
For: SYSTEM AND METHOD FOR THREE-DIMENSIONAL
SURFACE INSPECTION

Enclosed are:

- ☒ Eighteen (18) pages of Patent Specification and Claim(s).
- ☒ Three (3) sheets of drawings.
- ☒ A Combined Declaration and Power of Attorney (unsigned).

Respectfully submitted,

Dated: NOVEMBER 19, 1999


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**SYSTEM AND METHOD FOR
THREE-DIMENSIONAL SURFACE INSPECTION**

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BACKGROUND OF THE INVENTION

Technical Field of the Invention

10 The present invention relates to the inspection of structures on an object and, more specifically, to a system and method for optically obtaining three-dimensional information regarding the position of structures on the surface of an object.

Description of Related Art

15 Optical inspection devices typically hold an object to be inspected under an overhead camera, and illuminate the object from a single or multiple light sources. Typically, the optical inspection device lights the object from several directions in order to fully illuminate the surface and any objects thereon. The overhead camera captures a two-dimensional

gray-scale (black-and-white) image of the object and structures. In a process commonly called convolution, this image is then sent to a computer which compares the image, pixel by pixel, to a stored image of an object with properly positioned structures thereon. If any differences
5 between the captured image and the image of the object with properly positioned structures are detected, the computer has detected a defective object. A typical application of this inspection technology is in the inspection of printed circuit boards (PCBs).

Other techniques for optical inspection such as the generation of
10 structure grammar from captured images, tracing of structures to produce a set of primitives for the structure edges, the use of alignment techniques utilizing histograms to compensate for vibration and wobble of the support mechanism, and methods of automatic defect classification are disclosed in co-owned and co-pending U.S. patent application number 09/262,603
15 entitled *System and Method of Optically Inspecting Structures on an Object*, and co-owned and co-pending U.S. patent application number 09/338,880 entitled *System and Method of Optically Inspecting Surface Structures on an Object*, both of which are hereby incorporated by reference herein in their entireties.

20 Existing optical inspection systems and methods are becoming very efficient at obtaining and analyzing surface structures and defects which reveal themselves in the two dimensions of the surface of the object.

However, there is still a problem in rapidly and efficiently obtaining detailed and accurate information about the height of the structures. Some prior art systems have used lasers to obtain height information. When a laser is pointed at a particular point on the surface of the object, a small dot is formed by the laser beam. If the angle of incidence of the laser beam is less than 90 degrees, and there is a structure at this point, the dot is displaced horizontally from the position where the dot would be if there was no structure. The taller the structure, the greater the displacement. The vertically mounted camera can then detect the displacement of the laser dot, and height information can be computed from the magnitude of the displacement. However, this is a slow and inefficient process which is not suitable for obtaining height information over the entire surface of the object.

In order to overcome the disadvantage of existing solutions, it would be advantageous to have a system and method of rapidly and efficiently obtaining three-dimensional information regarding the position of structures on the surface of an object. The present invention provides such a system and method.

SUMMARY OF THE INVENTION

In one aspect, the present invention is an optical inspection system for inspecting at least one structure on a surface of an object. The system includes a first visual light source which illuminates the surface of the object and the structure with a light at a first visual frequency, and a first
5 laser light source which illuminates the surface of the object with a narrow coherent laser beam simultaneously with illumination by the first visual light source. The laser beam is emitted at a second visual frequency that is different from the first visual frequency of the visual light source. The first laser light source is mounted off vertical on a movable mount which
10 enables the laser beam to be directed over an area of interest on the surface of the object. The system also includes a color scan camera mounted vertically above the object. The camera has a first channel which captures an image of the illuminated surface of the object and the structure at the first visual frequency, and a second channel which captures a path
15 of the laser beam as it strikes the surface of the object and the structure at the second visual frequency. A computer then determines two-dimensional structure information from the image at the first visual frequency, and determines height information for the structure from the path of the laser beam at the second visual frequency. The system may
20 also include a second visual light source mounted on an opposite side of the object and illuminating the object at a third visual frequency.

Additionally, the system may include a second laser light source oriented 90 degrees from the first laser light source.

5 In another aspect, the present invention is a method of inspecting at least one structure on a surface of an object. The method includes the steps of illuminating the surface of the object and the structure with a first visual light at a first visual frequency, and simultaneously illuminating the surface of the object with a first narrow coherent laser beam at a second visual frequency that is different from the first visual frequency. The first laser beam strikes the surface of the object at an angle of incidence less than 90 degrees. The laser beam is directed in a path covering an area of interest on the surface of the object. This is followed by capturing an image of the illuminated surface of the object and the structure at the first visual frequency utilizing a first channel of a color scan camera mounted vertically above the object. Simultaneously, the path of the laser beam at 10 the second visual frequency is captured utilizing a second channel of the color scan camera as the laser beam strikes the surface of the object and the structure. Two-dimensional structure information is then determined from the image at the first visual frequency, and height information for the structure is determined from the path of the laser beam at the second visual frequency. 15 20

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood and its numerous objects and advantages will become more apparent to those skilled in the art by reference to the following drawings, in conjunction with the accompanying specification, in which:

FIG. 1 is a simplified block diagram of a three-dimensional optical inspection system;

FIG. 2 is an illustrative drawing of a component mounted on the surface of a printed circuit board (PCB) illustrating the height-measurement technique of the present invention; and

FIG. 3 is a flow chart illustrating the steps of the method of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

The present invention advantageously combines several new inspection techniques in order to rapidly and efficiently obtain three-dimensional information regarding the position of structures on the surface of an object. The exemplary embodiment described herein is discussed in the context of a PCB inspection system. However, the system and method described herein may also be utilized to inspect other types of structures and objects.

FIG. 1 is a simplified block diagram of a three-dimensional optical inspection system 10. The present invention utilizes laser light and multi-spectrum visual light together at the same time. A PCB 11 with components 12, or other formations such as solder blocks, on its surface is supported on a support mechanism 13. Two multi-spectrum visual lights 14 and 15 illuminate the PCB from opposite sides. Light 14 may be, for example green, while light 15 is blue. Two coherent red-light lasers 16 and 17 are mounted off the vertical (i.e., the angle of incidence of their laser beams is less than 90 degrees), and are mounted approximately 90 degrees apart horizontally. Thus, if laser 16 points at the PCB from the front, laser 17 may point at the PCB from the right side or the left side. The lasers are mounted on movable mounts 18 and 19, enabling the lasers to be pointed at any point on the PCB surface.

A color scan camera 20 is mounted above the PCB surface. The color scan camera performs a high speed scan of the PCB surface and utilizes red, green, and blue (RGB) channels to separate the signals of the laser light and the multi-spectrum visual lights.

The inspection system is under the control of a control computer 21. The control computer, or another dedicated computer, may also generate structure grammar from captured images, trace structures to produce sets of primitives for the structure edges, align multiple images utilizing histograms to compensate for vibration and wobble of the support

mechanism, perform height calculations, and perform automatic defect classification.

In operation, the green light 14 and the blue light 15 are used to illuminate the entire surface of the PCB. Simultaneously, the two coherent
5 red-light lasers 16 and 17 are used to generate a series of parallel lines over the surface of the PCB 11. The lasers are mounted at 90 degree positions from each other and generate a grid of perpendicular red lines on the PCB surface. In addition, the lasers are strobed at a predetermined rate, so that both time-multiplexing and color-multiplexing can be used to
10 separate the laser signal from the visual light signals generated by the green light and the blue light. The color scan camera utilizes its red, green, and blue channels to separate the red, green, and blue signals from the various light sources.

The color scan camera 20 is controlled to point at the same position
15 as one or both of the lasers. Then the camera and the laser are scanned together over the surface of the PCB and take height readings across the PCB. By using the laser grid lines, the present invention can obtain height information over the entire surface of the PCB in a single high-speed scan. When a laser grid line encounters an object on the surface of the PCB,
20 there is a discontinuity in the laser grid line. The magnitude of the discontinuity is measured in order to determine the height of the object.

The color scan camera takes a continuous series of exposures as it scans. By controlling the exposure time, the resolution of the height information in the direction of the laser line is controlled. A very short exposure time provides a height reading for a desired point on the surface. A rapid series of short exposures provides a height profile over a region of the surface. For longer exposure times, a series of height measurements may be integrated to provide an average height over the entire surface or a region thereof.

FIG. 2 is an illustrative drawing of a component 12 mounted on the surface of the PCB 11 illustrating the height-measurement technique of the present invention. Portions of two laser lines 31 and 32 are shown as they cross over the component 12. Dotted lines 33 and 34 illustrate the imaginary positions that lines 31 and 32 would present to the camera 20 if the structure was not present. Lines 31 and 32 are displaced from dotted lines 33 and 34 by distance "d". The displacement distance is dependent on the height of the structure and the angle by which the laser is mounted off the vertical. When the laser is mounted farther off the vertical, smaller height differences cause a greater displacement. Therefore, smaller height differences can be detected.

FIG. 3 is a flow chart illustrating the steps of the method of the present invention. At step 41, the PCB 11 to be inspected is positioned on the support mechanism 13. At step 42, the PCB is illuminated with blue

visual light, green visual light, and red laser light. At step 43, the color scan camera 20 is aligned with the position of one of the lasers 16 and 17. The color scan camera and the laser are then scanned together across the surface of the PCB at 44. The color scan camera uses its red, green, and blue channels to separate the signals from the three light sources. The red signal may be further differentiated, as noted above, by strobing the laser and using time-multiplexing to extract the signal. At 45, the signals from the green and blue channels are analyzed using known techniques to obtain two-dimensional information regarding the structure of the component mounted on the PCB. At 46, the signal from the red channel is analyzed using the techniques illustrated in FIG. 2 to obtain height information for the component. As noted above, this information may be utilized to determine a height profile, or the information may be integrated over a period of time at step 47 to obtain an average height value.

By utilizing the method of the present invention, the present invention can obtain three-dimensional structure information over the entire surface of the PCB in a single high-speed scan.

It is thus believed that the operation and construction of the present invention will be apparent from the foregoing description. While the system and method shown and described has been characterized as being preferred, it will be readily apparent that various changes and

modifications could be made therein without departing from the scope of the invention as defined in the following claims.

WHAT IS CLAIMED IS:

1 1. An optical inspection system for inspecting at least one
2 structure on a surface of an object, said system comprising:
3 a first visual light source which illuminates the surface of the object
4 and the structure with a light at a first visual frequency;
5 a first laser light source which illuminates the surface of the object
6 with a narrow coherent laser beam simultaneously with illumination by the
7 first visual light source, said laser beam being at a second visual frequency
8 that is different from the first visual frequency of the visual light source,
9 said first laser light source being mounted off vertical on a movable mount
10 which enables the laser beam to be directed over an area of interest on the
11 surface of the object;
12 a color scan camera mounted vertically above the object, said
13 camera having a first channel which captures an image of the illuminated
14 surface of the object and the structure at the first visual frequency, and a
15 second channel which captures a path of the laser beam as it strikes the
16 surface of the object and the structure at the second visual frequency; and
17 a computer which determines two-dimensional structure information
18 from the image at the first visual frequency, and determines height
19 information for the structure from the path of the laser beam at the second
20 visual frequency.

1 2. The optical inspection system of claim 1 further comprising
2 a second visual light source mounted on an opposite side of the object
3 from the first visual light source, said second visual light source
4 illuminating the surface of the object and the structure with a light at a
5 third visual frequency.

1 3. The optical inspection system of claim 2 wherein the color
2 scan camera includes a third channel which captures an image of the
3 illuminated surface of the object and the structure at the third visual
4 frequency.

1 4. The optical inspection system of claim 3 wherein the
2 computer also determines two-dimensional structure information from the
3 image at the third visual frequency.

1 5. The optical inspection system of claim 4 wherein the color
2 scan camera includes means for making a continuous series of exposures
3 as the camera scans the surface of the object.

1 6. The optical inspection system of claim 5 wherein the means
2 in the color scan camera for making a continuous series of exposures
3 includes means for varying the length of each exposure.

1 7. The optical inspection system of claim 6 wherein the
2 computer includes means for integrating the height information over the
3 length of an exposure to calculate an average height.

1 8. The optical inspection system of claim 1 further comprising
2 a second laser light source mounted on a side of the object which is
3 displaced 90 degrees from the first laser light source, said second laser
4 light source illuminating the surface of the object in a path that is
5 perpendicular to the path illuminated by the first laser light source.

1 9. A method of inspecting at least one structure on a surface of
2 an object, said method comprising the steps of:

3 illuminating the surface of the object and the structure with a first
4 visual light at a first visual frequency;

5 simultaneously illuminating the surface of the object with a first
6 narrow coherent laser beam at a second visual frequency that is different
7 from the first visual frequency, said first laser beam striking the surface of
8 the object at an angle of incidence less than 90 degrees;

9 directing the laser beam in a path covering an area of interest on the
10 surface of the object;
11 capturing an image of the illuminated surface of the object and the
12 structure at the first visual frequency utilizing a first channel of a color
13 scan camera mounted vertically above the object;
14 simultaneously capturing the path of the laser beam at the second
15 visual frequency utilizing a second channel of the color scan camera as the
16 laser beam strikes the surface of the object and the structure;
17 determining two-dimensional structure information from the image
18 at the first visual frequency; and
19 determining height information for the structure from the path of the
20 laser beam at the second visual frequency.

1 10. The method of inspecting at least one structure on a surface
2 of an object of claim 9 further comprising illuminating the surface of the
3 object and the structure with a second visual light at a third visual
4 frequency, the second visual light being mounted on an opposite side of
5 the object from the first visual light.

1 11. The method of inspecting at least one structure on a surface
2 of an object of claim 10 further comprising simultaneously capturing an
3 image of the illuminated surface of the object and the structure at the third
4 visual frequency utilizing a third channel of the color scan camera.

1 12. The method of inspecting at least one structure on a surface
2 of an object of claim 11 further comprising determining two-dimensional
3 structure information from the image at the third visual frequency.

1 13. The method of inspecting at least one structure on a surface
2 of an object of claim 12 wherein the step of simultaneously capturing the
3 path of the laser beam includes making a continuous series of exposures
4 with the color scan camera as the camera scans the surface of the object.

1 14. The method of inspecting at least one structure on a surface
2 of an object of claim 13 wherein the step of making a continuous series of
3 exposures includes varying the length of each exposure.

1 15. The method of inspecting at least one structure on a surface
2 of an object of claim 14 further comprising integrating the height
3 information over the length of an exposure to calculate an average height.

1 16. The method of inspecting at least one structure on a surface
2 of an object of claim 9 further comprising illuminating the surface of the
3 object with a second laser light source mounted on a side of the object
4 which is displaced 90 degrees from the first laser light source, said second
5 laser light source illuminating the surface in a path that is perpendicular to
6 the path illuminated by the first laser light source.

ABSTRACT OF THE DISCLOSURE

An optical inspection system and method for inspecting a component on a printed circuit board (PCB) which determines three-dimensional information in a single scan. A first visual light source illuminates the PCB surface and component with a green light while a
5 second visual light source illuminates the PCB and component with a blue light. At least one laser light source simultaneously illuminates the surface of the PCB with a narrow coherent red-light laser beam. The laser light source is mounted off vertical on a movable mount which enables the laser beam to be directed over an area of interest on the surface of the PCB.
10 The system also includes a color scan camera mounted vertically above the PCB. The camera has red, green, and blue channels. The green and blue channels capture an image of the illuminated surface of the PCB which is used by a computer to determine two-dimensional information about the component. The red channel captures a path of the laser beam as it strikes
15 the surface of the PCB and the component. The computer uses the path to determine height information for the component.

FIG. 1

10

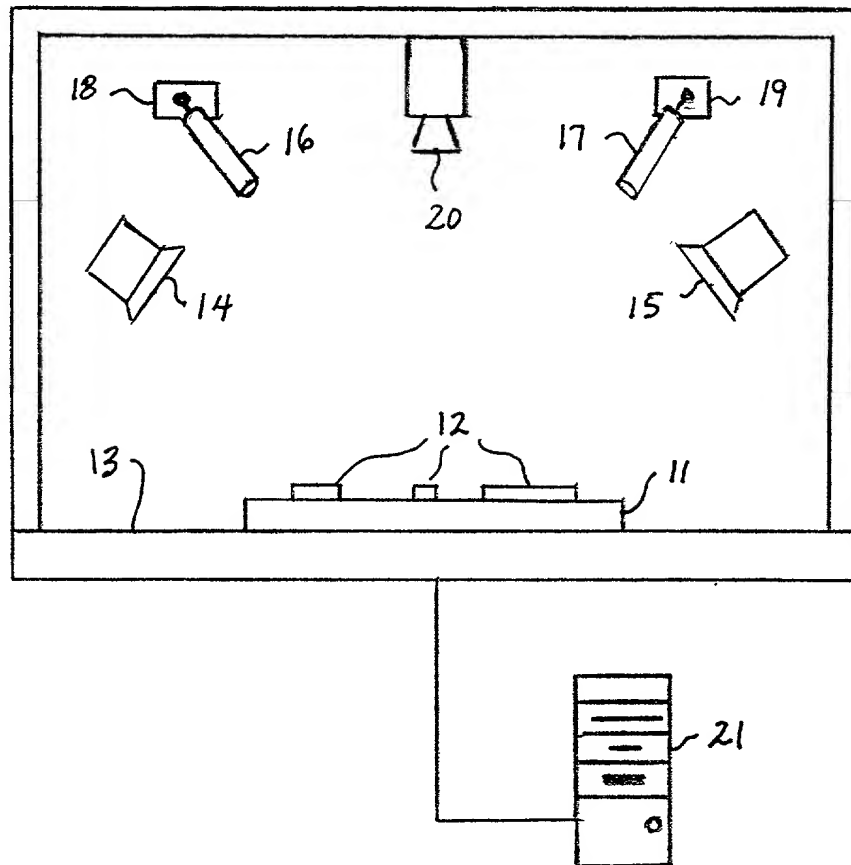


FIG. 2

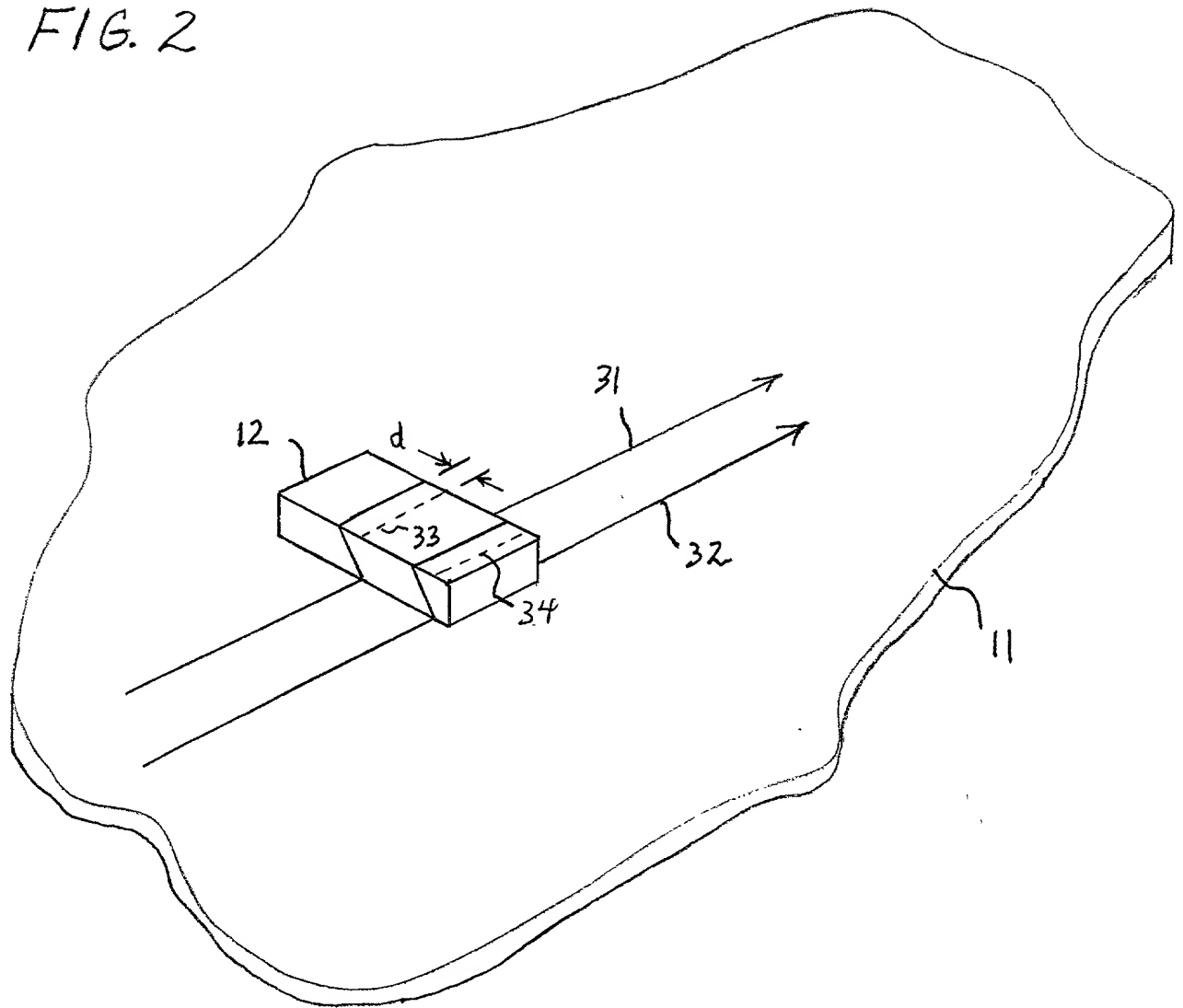
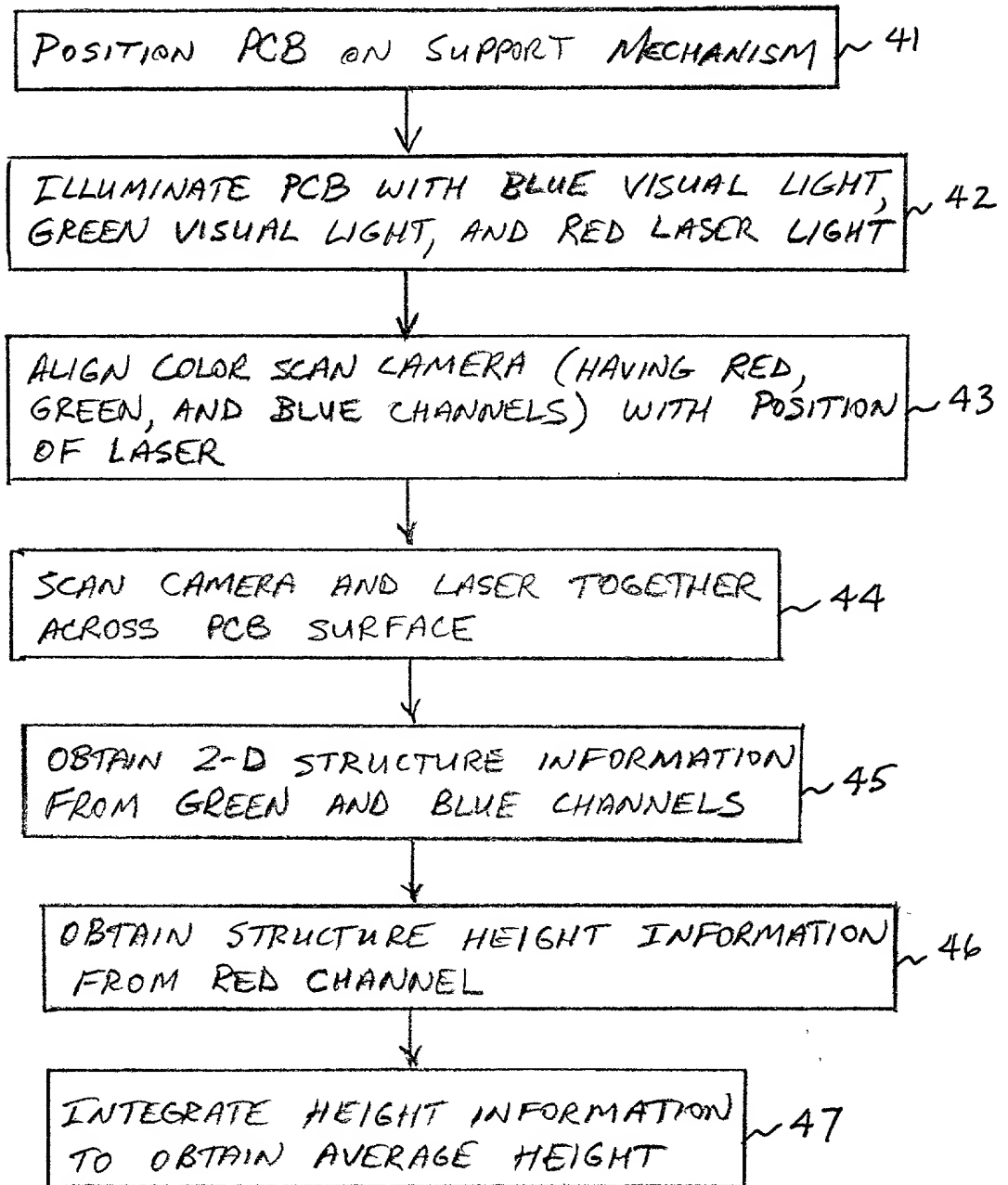


FIG. 3



COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name; and

I verily believe that I am an original, first, and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled:

SYSTEM AND METHOD FOR THREE-DIMENSIONAL SURFACE INSPECTION

the specification of which:

___ is attached hereto.

___ was filed on _____ as Application Serial No. _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the Office all information known to me to be material to the patentability of this application as defined in 37 CFR § 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of any application on which priority is claimed:

Country	Number	Date Filed	Priority Claimed
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

I hereby claim the benefit under 35 U.S.C. § 120/365/119 and 37 CFR § 1.78 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose material information as defined in 37 CFR § 1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

Application Serial No.	Filing Date	Status (patented, pending)
_____	_____	_____
_____	_____	_____
_____	_____	_____

I hereby appoint the following attorneys and/or agents to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: STEVEN W. SMITH, Reg. No. 36,684 and SHREEN K. DANAMRAJ, Reg. No. 41,696 of the firm of Smith & Danamraj, P.C., 12900 Preston Road, Suite 1200, LB-15, Dallas, Texas 75230-1328.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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